X-611-64-329

NASA TM X-55147

LOW ENERGY CHARGED PARTICLE DETECTION USING THE CONTINUOUS CHANNEL ELECTRON MULTIPLIER

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NOVEMBER 1964

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Presented at IEEE 11th Annual Nuclear Science Symposium
Philadelphia, October 28-30, 1964

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ABSTRACT

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It has been found to be possible to operate the continuous channel electron multiplier, a recently developed type of windowless electron multiplier, in a gain saturated mode such than single charged particles entering the input mouth of the channel will initiate output pulses whose amplitude and shape are both uniform and independent of the character of the excitation radiation. By suitable design of the channel this saturated pulse can be made stable against changes in such operating conditions as ambient pressure and applied voltage. Some degradation in the pulse height distribution is noted at very high count rates but operation for short periods at count rates of at least 10^5 per second is possible. When operated in this mode the efficiency of the channel for the detection of electrons over the energy range 250 eV to 10 keV is estimated to be greater than 50%. The channel multiplier has been used as the detector in rocket borne low energy electron spectrometers to obtain the energy spectrum of the auroral electrons. Data indicates that the operation of the detectors was as expected.

AUTHOR

Introduction

It has been recognized that the role of low energy charged particles is a very important one in explaining and understanding the dynamics of the charged particle population near the earth and of the interaction between solar processes and these particles. For example, J. Freeman has found, using cadmium sulfide crystal detectors, large energy fluxes of low energy trapped particles and large variations in these fluxes associated with geomagnetic and solar activity.

C. Snyder, et. al. has measured the charged particle stream comprising the "solar wind" and found them to possess energies in the hundreds to thousands of eV range. Sudden increases in the average energy and fluxes of these particles were observed and correlated with the subsequent occurance of geomagnetic activity on the earth.

On the basis of the observed altitude distribution of the luminosity of auroral forms this phenomena has long believed to be due to the influx of relatively low energy charged particles. This has been directly confirmed by rocket measurements of C. McIlwain and others. Balloon observations, however, indicate that often quite energetic electrons (hundreds of keV) accompany such precipitation.

The qualitative measurements of the intensity and energy spectrum of particles in this energy range has been hampered by the lack of suitable detectors. Techniques, such as continuous gas flow Geiger counters, refrigerated scintillation-phototube detectors, liquid scintillators, and the like, that are used in the laboratory to measure these particles are either impossible or extremely difficult to use on sounding rocket or satellite experiments.

Total energy flux detectors such as cadmium sulfide crystals or thin scintillators-where the gross light output of the scintillator is measured have been used in space science experiments and have given data on this parameter. Total particle flux detectors such as bare electron multipliers or charged particle traps used in conjunction with electrostatic energy analyzers have also been flown but are either relatively bulky or lack sensitivity.

Description of the Present Work

Recently a windowless electron multiplier, the continuous channel electron multiplier (Channeltron) has been developed at the Bendix Research Laboratories. Because its small size and simplicity would make it an ideal tool in space research, an investigation was undertaken at GSFC to determine its suitability for the detection of low energy charged particles.

The operation of the channel multiplier has been fully described by Wiley and Hendee, and many of its characteristics have been outlined by Angel, et.al. Briefly, the channel multiplier is a capillary tube in which the multiplication of electrons occurs on the interior walls of the tube, the electrons acquiring their energy from an axial electric field established down the tube by a potential difference applied from one end of the tube to the other (Fig. 1). The electron cascade resulting from the initial emission of electrons by ultraviolet light or charged particles incident into the open mouth of the tube may be collected at the high potential or output end in either the analog fashion of measuring the output current or, if the electron gain is sufficient, counting the individual pulses. The material put on the surface of the glass tube and used as the secondary emission material has the two significant advantages of being stable against extended exposure to air and of having a high work function-resulting in both a lack of sensitivity to light of wavelengths longer than about 2000 Å and an absence of a thermal noise background level.

The work at Goddard has departed from prior investigations of the channel by Wiley and Hendee and Angel et. al. in that the effort has been directed toward operation in a high electron gain mode such that the output pulses may be counted individually. The experimental arrangement normally used is shown in figure 2.

The initial work was done utilizing straight channel multipliers having length-to-inside diameter ratios ranging from 50 to 100. However, the necessity of operating the channel multiplier at electron gains of up to 10^7 has led to the design of a curved channel multiplier to prevent instability effects associated with regenerative positive ion feedback. The multipliers presently used at Goddard are in the form of a capillary tube 10 cm long with a 1 mm inside diameter and curved through a 270° arc. This geometry permits stable operation at large electron gains at ambient pressures well above 0.5 microns of Hg thus making the device suitable for use in sounding rocket experiments and easing the problems in laboratory calibration and investigation.

It was found that the operation of the channel multiplier in this high gain mode has the unique result that the output pulses resulting from individual charged particles entering the mouth of the tube exhibit a strongly peaked pulse height distribution. These pulses are of such amplitude that conventional pulse counting and threshold discrimination techniques may be easily used. Moreover, this output pulse height distribution is of such a nature that, with proper setting of the counting circuit discrimination levels, relatively large changes in the channel electron gain due to fatiguing, ageing, or drifts in the applied voltage, if they should occur, will not affect the particle counting efficiency of the detector. In this sense the mode of operation is suggestive to that of a Geiger-Müller tube as is exemplified by the count rate plateau curve shown in figure 3.

The appearance of such uniform amplitude output pulses at very large electron gains is ascribed to a saturating of the electron multiplication process leading to a self limiting of the gain. This saturation is believed to come about from the distortion of the axial electric field by the positive surface charge density produced upon the interior surface of the channel as a direct result of the electron multiplication process. In this manner a potential gradiant which is not conducive to electron multiplication can be created over the collection end portion of the tube thus limiting the gain. A consequence of this model is the occurance of a counting dead time while the perturbed potential distribution in the channel returns to normal with the redistribution of the surface charge over the appropriate RC relaxation time. Such a dead time phenomena is observed as a reduction in the average output pulse height at count rates of about 10^5 per second. At still higher counting rates the peaked pulse height distribution deteriorates into a very broad distribution characteristic of lower electron gains in the channel.

The operation of the channel multiplier at lower gains, thus avoiding the large distortions is the electric field, would allow higher count rates to be obtained without the channel "loading up." However, this method of achieving a wider dynamic range requires, in general, that the peaked pulse height distribution be sacrificed and a broad pulse height distribution, much more sensitive to gain drifts or threshold level settings, be tolerated.

In contrast with the dead time the output pulse itself exhibits a rise time of about 10 nanoseconds and a decay time which is set by the RC of the output or collection circuit. Normally in work at Goddard an emitter follower is utilized at the output of the channel in order to drive the shunt capacity of the cabling, and pulse amplitudes of 600 mv and widths of 0.2 microseconds are typically observed.

The particle counting efficiency of the channel multiplier is dependent upon two factors; first on the probability that the incident particle will produce one or more secondary electrons at the input mouth of the tube, and secondly upon the efficiency with which these initial electrons can produce a saturated output pulse (collection efficiency).

On the basis of investigations of the counter efficiency using radioactive beta and x-ray sources, the collection efficiency for single initial electrons is believed to be in the range of 60-80%. Thus, the dependence of the counting efficiency upon the energy and type of incident radiation is governed by the secondary electron emission ratio appropriate to the incoming particles striking the channel surface, a ratio which is generally relatively high for positive ions and which may range for electrons from somewhat larger than 1.0 to less than 0.1.

Hence, one may conclude that the counting efficiency of the detector for incident protons having energies greater than some 100 eV is quite high (approaching unity) and remains high for proton energies of up to hundreds of keV. The existence of a high counting efficiency for energetic ions has been confirmed using alpha particle sources.

For electrons, on the other hand, the counting efficiency would exhibit a peak for incident energies around 1 keV and slowly decline with increasing energy - reflecting a decline of the secondary emission ratio with increasing electron energy. Experiments were performed to determine directly the counting efficiency for electrons in the tens of keV range. A high voltage, hot filament arrangement was used to obtain the variable energy electron beam, and a sensitive electrometer used to measure the electron current incident into the channel multiplier mouth. The resulting count rate was then compared with the input current to obtain the efficiency. The measurements for electrons of 50 keV indicate an efficiency of about 30% while at 10 keV the efficiency was about 60% thus displaying the qualitative behavior predicted by secondary electron emission data.

Although the measurements of the input currents are uncertain due to the use of very low input particle fluxes to avoid dead time effects in the channel, the results are in good agreement with those estimated from experiments performed with Ni-63 (average energy $\approx$ 20 keV) and S-35 (average energy $\approx$ 60 keV) beta sources. Hence the quoted efficiencies are believed to be reasonably accurate.

Long term drifts in the electron gain of the channel with use - of critical importance insofar as satellite applications are concerned - are difficult to expose unambiguously during operation in laboratory vacuum systems as contamination, even when liquid nitrogen cold trapped systems are used, may become the major cause of gain degradation. Indeed, the observed gradual decline in the electron gain of the channel after operation at a modest count rate for a period of weeks in diffusion pump vacuum systems is found to be reversible, not by "rest" as is the remedy for fatigue in photomultiplier tubes, but through cleaning procedures. This is taken to indicate that the secondary emission ratio of the multiplier surface was being altered through contamination by pump oil chemically decomposed by the cascade electrons. Study of long term degradation would need to be carried out in very clean static vacuum systems or in oil-less dynamic systems to be meaningful.

Because the pulse itself from the channel multiplier carries no information as to the type or energy of the incident particle, in general separate pre-analysis of the incoming particle flux must be introduced into any experiment to define these factors. Figure 4 illustrates one approach to this problem - a bending magnet differential energy spectrometer developed to detect electrons in the 2-20 keV energy range and used on sounding rocket payloads launched to investigate the energy spectra of auroral electrons. Figure 5 is a calculated geometric factor vs. incident electron energy curve (weighted for an isotropic particle flux) and gives an indication of the energy resolution of such a system. The characteristics of the energy pass band were confirmed in actual calibrations with electron beams.

Four such detector modules were included in the rocket payload, one in a shielded background configuration and the remaining three, their energy acceptance bands adjusted by magnet selection, exposed directly to the incoming auroral particles. Figure 6 displays the raw count rate history of the three exposed detectors during NASA flight 14.118, launched on March 23, 1964 into post-breakup type aurora.

The following points together indicate that the detector systems were operating properly and producing valid data.

1. The channel multiplier is responding to incoming radiation by an altitude of 100 km, i.e. an ambient atmospheric pressure of about 0.3 micron. This is consistent both with the atmospheric absorption of the incident radiation and the maximum pressure for which the channel will operate (allowing a time lag for exhausting the air from the payload).

2. The peaks in count rate are reproduced simultaneously and in great detail by all three detectors. These peaks correspond in time to periods of enhanced auroral luminousity and ionospheric disturbance.

3. The count rate peaks registered by the channel multipliers are coincident in time to the response of a total energy scintillation detector carried in the payload. This lends assurance that the channel multiplier detectors were indeed responding to an influx of radiation.

4. The background channel multiplier, although showing increases during periods of large particle influx, had maximum count rates of about 100 cps, 1% of the response of the 3.2 keV channel multiplier. Thus abnormalities in the 3000 volt power supply driving the four channel multipliers may be eliminated as a cause of spurious count rate peaks.

5. By applying the best counting efficiency data available (0.4 for 25 keV, 0.6 for 10 keV, and 0.7 for 3.2 keV) electron energy spectrum may be extracted from the data. These spectra are in good agreement with spectra previously found for auroral electron precipitation. Moreover, the total energy influxes inferred from the data are also in agreement with those fluxes normally associated with auroras of the intensity that were observed during the flight.

6. From details of the steep decrease in counting rate between +340 sec. and +350 sec. (caused by the atmospheric absorption of the incident electrons) a rough determination of the average energy of the electron beam may be made. Such an analysis gives an average energy on the order of 10 to 20 keV. This is in good agreement with the energy spectrum determined directly from the three individual channels at +330 seconds, just prior to re-entering the atmosphere.

In conclusion it has been found that the continuous channel electron multiplier, when operated in the saturated pulse mode, can provide a straight forward and convenient means of detecting low energy charged particles both in the laboratory and in sounding rocket experiments. The success of the device in long lived satellite experiments primarily depends, at this point, on its long term stability characteristics which, in the absence of contamination, are believed to be good.

ACKNOWLEDGEMENTS

Discussions with C. F. Hendee, G. Goodrich, and K. Schmidt of the Bendix Research Laboratories have been greatly appreciated. This work was performed while the author was the recipient of a National Academy of Science - NASA Postdoctoral Fellowship.

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FIGURE CAPTIONS

FIG 1. A schematic of the electron multiplication process in a channel multiplier (after Wiley and Hendee).

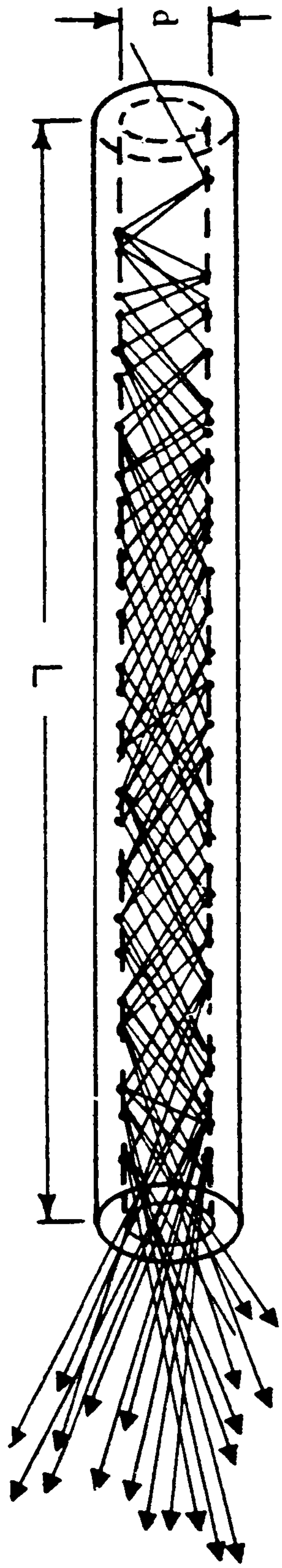
FIG 2. The experimental arrangement employed at Goddard for the investigation of the pulse mode of operation.

FIG 3. A count rate plateau curve obtained from a channel multiplier utilizing a Ni-63 beta source and counting electronics having a 100 mv pulse height threshold.

FIG 4. A schematic of a beta ray dispersion spectrometer employed on sounding rockets to detect low energy electrons.

FIG 5. The energy resolution of the analyzer system shown in figure 4.

FIG 6. The count rate history of three channel multipliers on a sounding rocket which passed through an aurora.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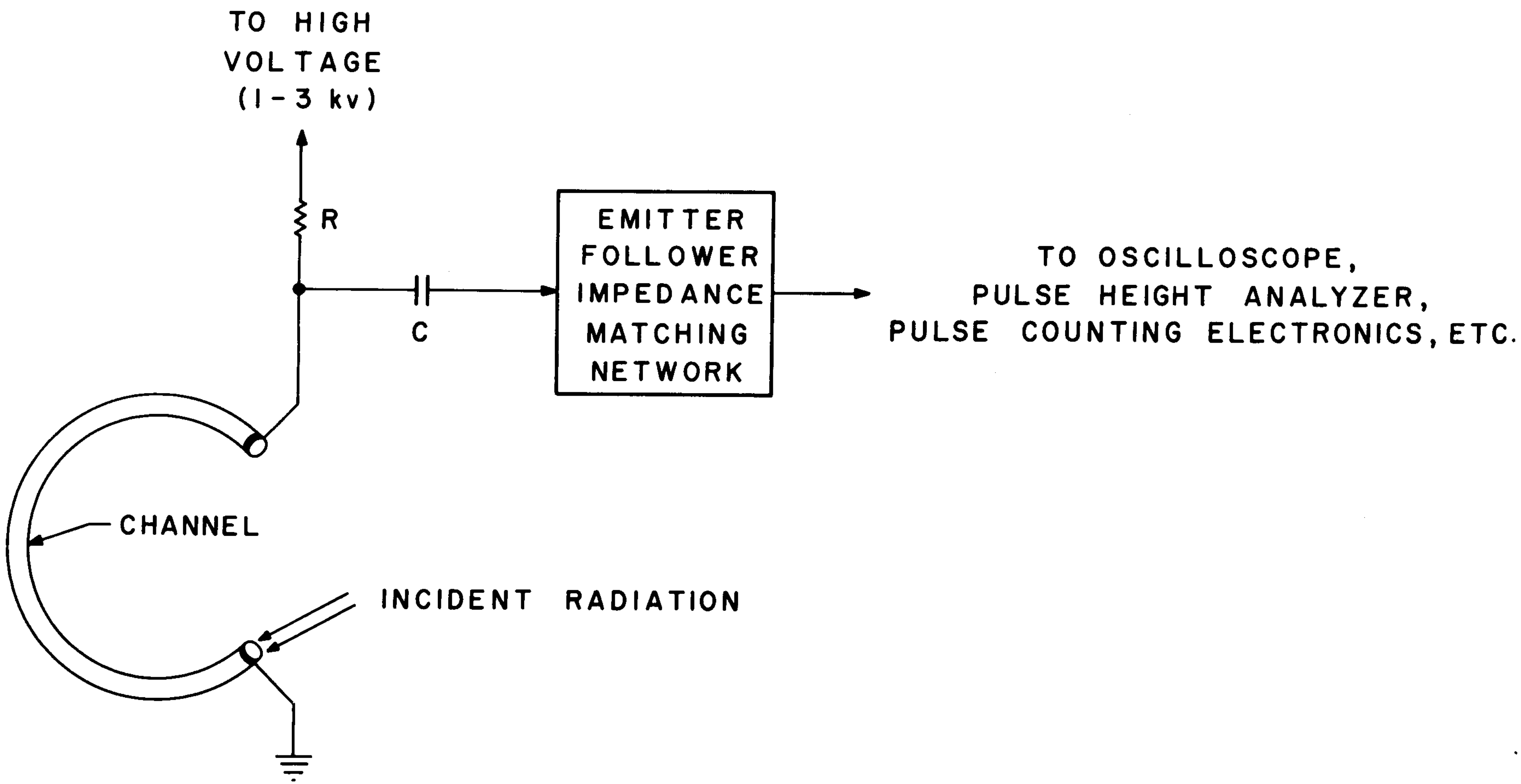
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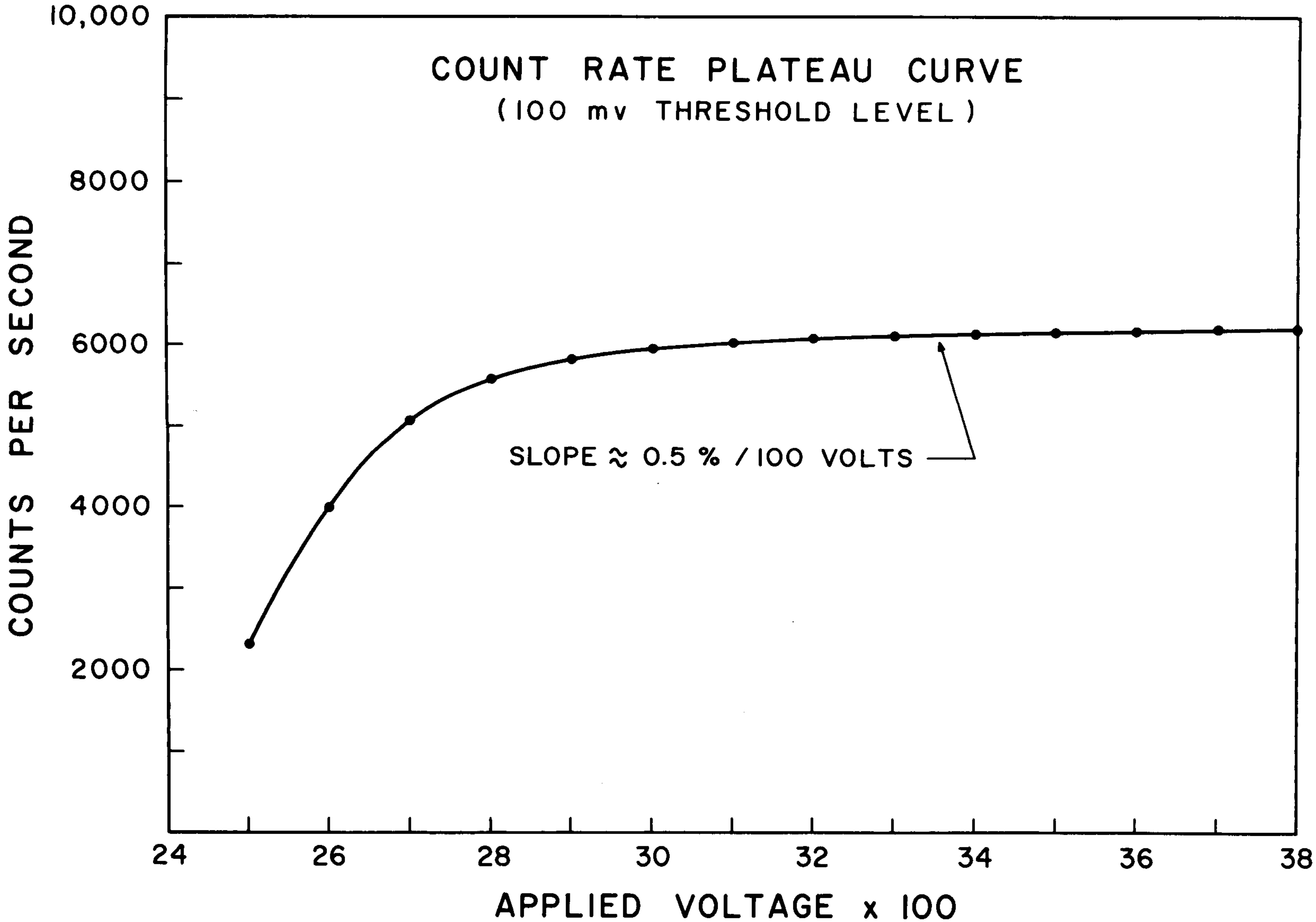
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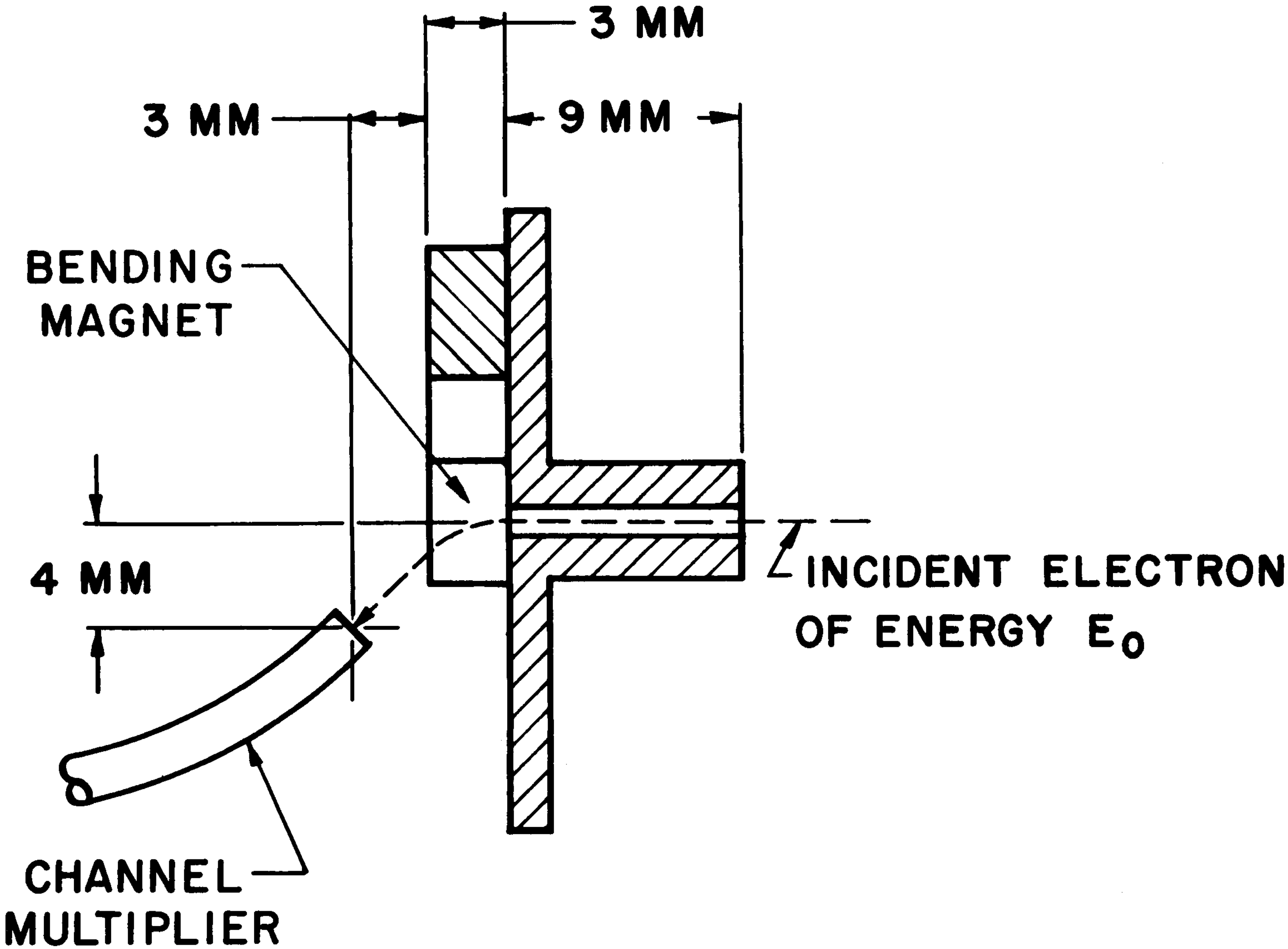

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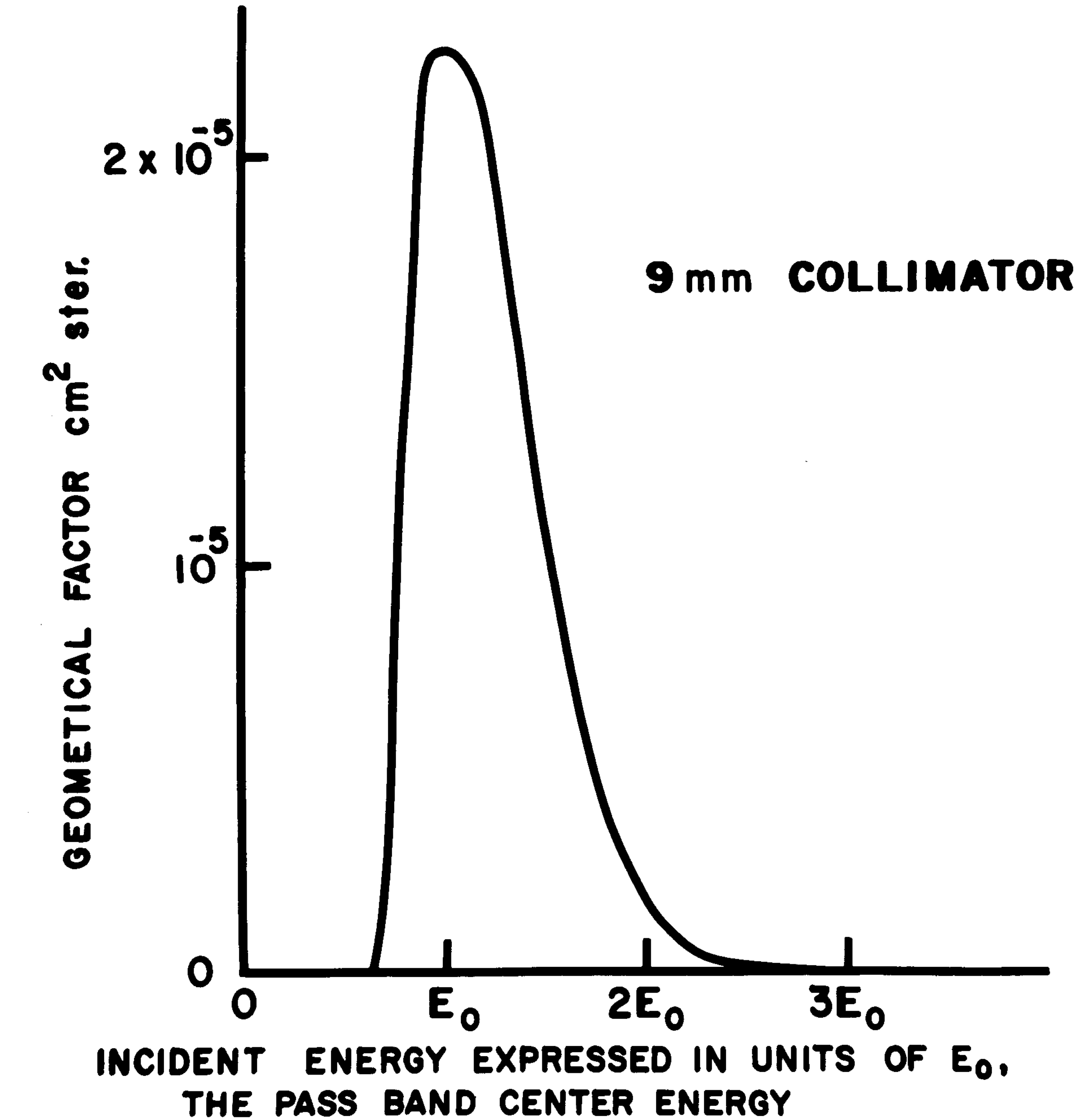
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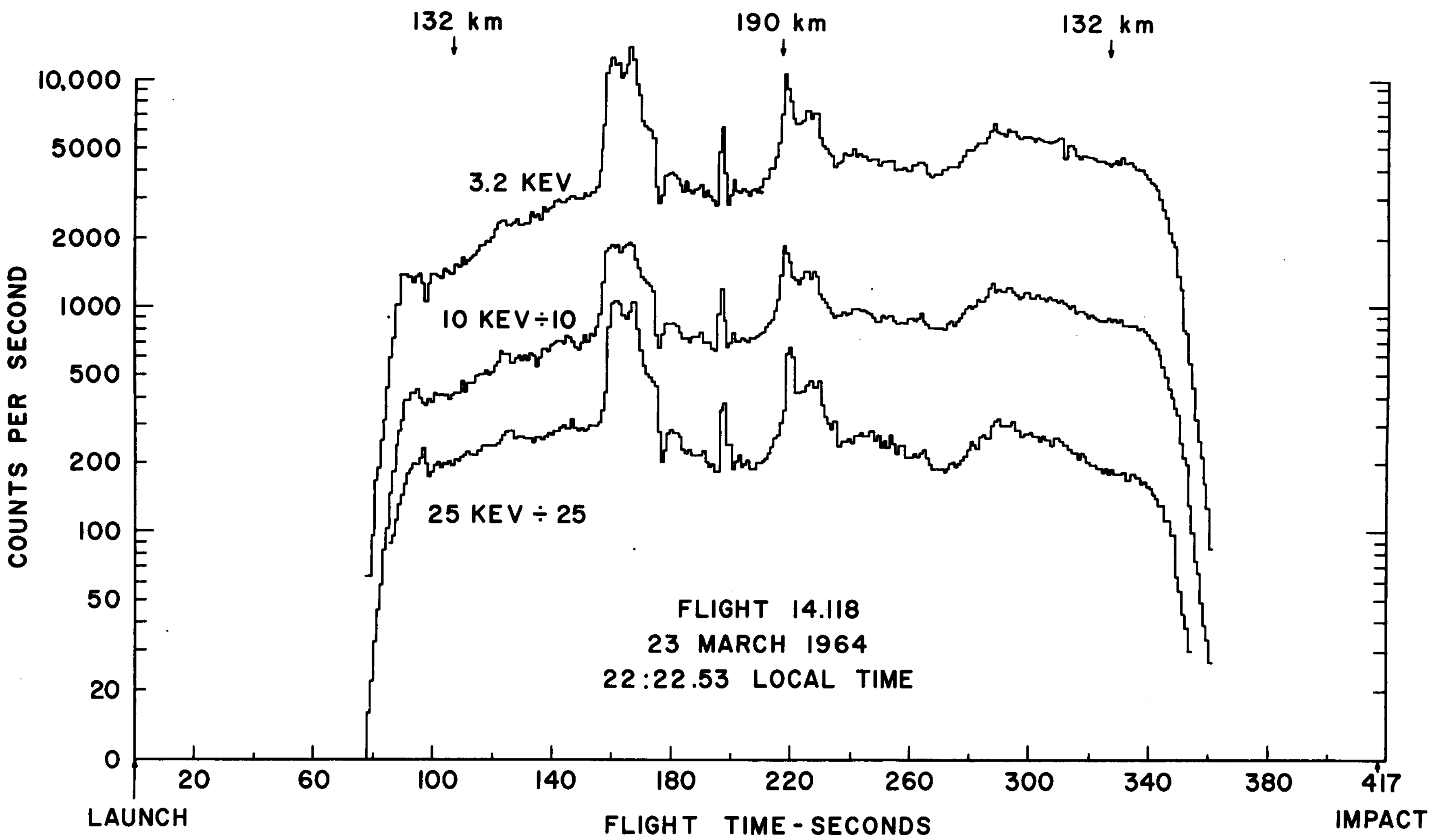
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